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A SIMPLIFIED METHOD FOR DETERMINATION OF BELOW GRADE HEAT LOSS

Prepared for

MONTANA DEPARTMENT of NATURAL RESOURCES and CONSERVATION

A SIMPLIFIED METHOD FOR DETERMINATION OF BELOW GRADE HEAT LOSS

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INTRODUCTION

The purpose of this study is to determine a simple method for describing heat loss in below grade components of residences in a variety of climates. The configurations discussed are the following:

1) full basements
2) shallow basements
3) crawlspaces
4) slab on grade

Both heated and unheated basements will be analyzed. Similarly, crawlspaces will be separated into vented and unvented structures. Study also will be made of the relative efficiency of all-weather wood foundations for crawl spaces. For each configuration, different R-values of insulation in the walls and floors will be analyzed.

The general procedure will be to determine simple "F-factors" such as those found in ASHRAE (1981) that may be multiplied by the exposed building perimeter length to result in a heat loss coefficient. This coefficient can then be used to estimate the correct annual heat loss rate in a standard heat loss methodology. This is similar to the approach taken by Wang (1981) that was adopted by ASHRAE.

F-factor methods, while permitting below grade components to be included in heat loss calculations, are not without problems. A major difficulty in the procedure is that heat loss below grade is related more to ground temperatures than to the exterior air temperatures commonly used in heat loss calculations (see Swinton and Platts 1981). Since heat loss in contact with the ground thermal regime is more constant than that of the exterior envelope, F-factor methods will tend to distort the variation of heat loss on a seasonal basis, commonly overpredicting winter losses and underpredicting summer ones. Since the usefulness of internal and solar gains are strongly tied to the building thermal load, this issue is of some importance. Furthermore, the loss coefficients generated by F-factor methods may be meaningless when applied to cooling energy load determination.

Although F-factors do not accurately represent the seasonal variation in below grade heat loss, the most important factor in the annual below grade thermal load is the mean annual ground temperature. This value is well correlated with average annual temperatures and heating degree days (HDD). Therefore, it is possible to accurately determine annual residential heat loads using such factors if one is not concerned with their seasonal distribution.

Although the F-factor method is useful for determining annual heating loads, the limited nature of the tables found in the 1981 ASHRAE <u>Handbook of Fundamentals</u> often results merely in use of a "fudge factor." Obviously, even the most rudimentary form of below grade heat loss calculations would be preferable.

APPROACH

Considerable research on below grade heat loss has been completed by various researchers, although most of it deals with only one configuration or another. Much of the work such as Akridge and Poulos (1983) has concentrated on determination of heat loss from below grade walls. However, for this task it is desirable to develop a consistent technique for evaluating below grade heat losses for the four described configurations.

The most recent work that is applicable to a number of configurations is that of Mitalas (1982) at the National Research Council of Canada and Shipp (1983) at the Owens Corning Fiberglas Corporation. Mitalas uses a detailed algorithm based on test results from several monitored basements and finite element computer models. This technique estimates heat loss for basements, shallow basements, or slab on grade configurations. Mitalas does not explicitly cover crawlspaces. Shipp, on the other hand, has used a complex numerical model to estimate correlation coefficients for some 26 different configurations, including all of the mentioned types. The simplified annual technique will use all three methods mentioned above for development of the F-factors. Generally the Shipp correlations for annual heating loads will be used to create the factors while the more detailed and complex Mitalas method will be used as a check to insure that the estimates are in general agreement. The decremented average ground temperature (DAGT) method (Akridge and Poulos 1983) will be used to analyze heated basements for comparison with the other

two methods (see page 13 for description). The analysis of crawlspaces will depend solely on the Shipp correlations, since the Mitalas or DAGT models do not explicitly cover this type.

This analysis will be performed on four prototype below grade configurations. All of the configurations will be below grade extensions of the 1,350-square-foot prototype house developed for the Northwest Power Planning Council in its analysis of residential energy conservation. A diagram of this simple house is shown in figure 1. The dimensions of the four below grade configurations are described in table 1 and graphically depicted in figures 2-5.

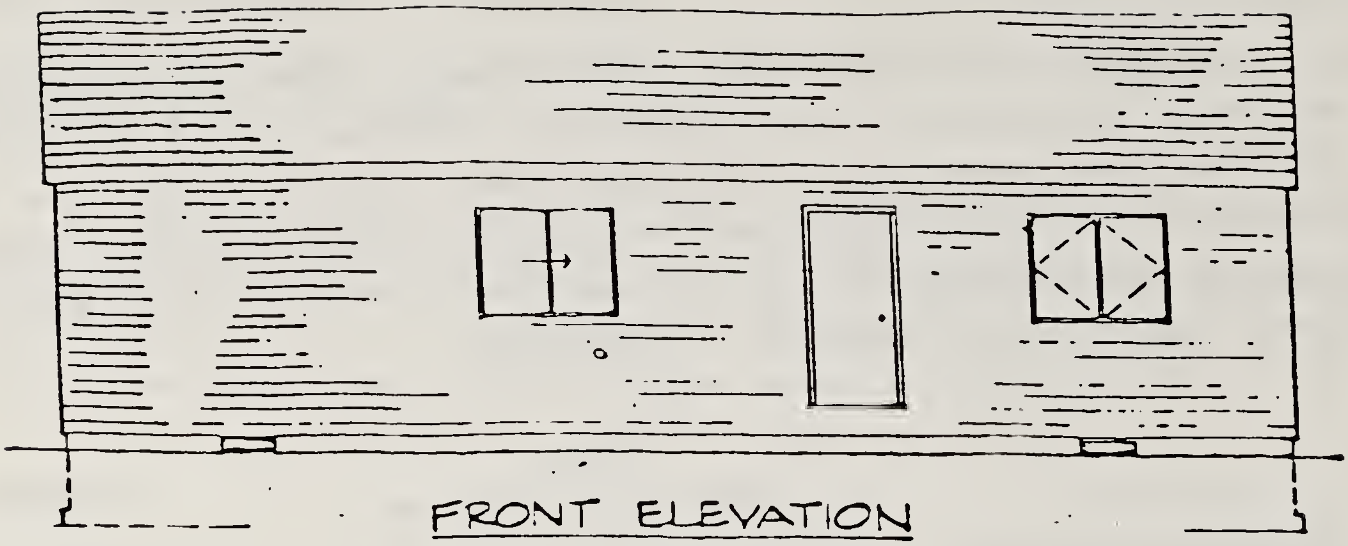
Table 1

BELOW GRADE PROTOTYPES

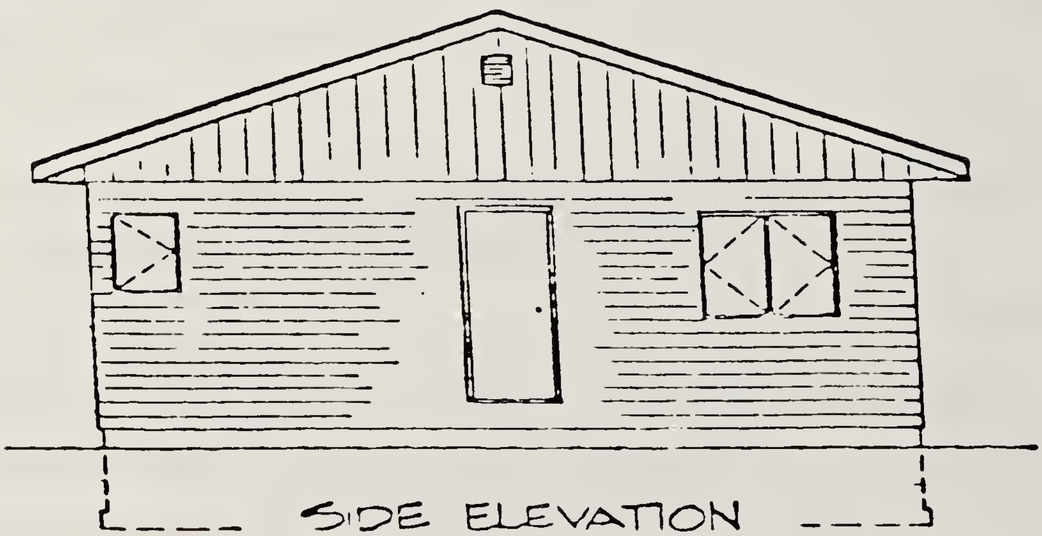
<u>All Cases Dimensions</u>	
Length	45 ft
Width	30 ft
Perimeter	150 ft
<u>Full Basement</u>	
Total wall height	8 ft
Depth below grade	7 ft
Height above grade	1 ft
Construction type	8" concrete wall and 4" floor or all-weather wood foundation (AWWF)
<u>Daylight Basement</u>	
Total wall height	8 ft
Depth below grade	4 ft
Height above grade	4 ft
Construction type	8" concrete wall and 4" floor
<u>Crawlspace</u>	
Total wall height	2.5 ft
Depth below grade	1.5 ft
Height above grade	1.0 ft
Construction type	2 x 4 blocking over 2 x 10 sill joists, 3 ft x 8" thick concrete stem wall or AWWF
<u>Slab on Grade</u>	
Construction type	5" concrete pad on ledge, cast into poured concrete 8"-thick stem wall

Figure 1

PROTOTYPE ABOVE GRADE HOUSE



FRONT ELEVATION



SIDE ELEVATION

The insulation configurations to be studied also vary by type and are listed below in table 2. Each configuration will be examined using different insulation levels, climates and soil conductivities. The R-values of the insulation will be the additive actual R-values of all materials covering the concrete wall (insulation, studs, sheetrock, etc.), not just the nominal value of the insulation alone.

Table 2

INSULATION CONFIGURATIONS

Basements

Uniform wall insulation
Wall insulation plus floor insulation
Unconditioned basements
All weather wood foundation

Daylight Basements

Uniform wall insulation
Wall insulation plus floor insulation

Crawlspaces

Insulated floor to living space (vented)
Insulated wall to exterior (unvented)
All-weather wood foundations

Slab on Grade

Vertical edge insulation to 4' depth
Horizontal perimeter insulation 4' wide
Edge insulation plus totally insulated floor

EVALUATION PARAMETERS

Heating Degree Days

Most currently used energy simulation models make use of a temperature differential over time. Heating degree days are the most simple form of this differential. The heating degree days at a given temperature can be computed using a correlation procedure developed by Erbs, Beckman, and Klein (1981). The calculation is as follows:

Figure 2

FULL BASEMENT

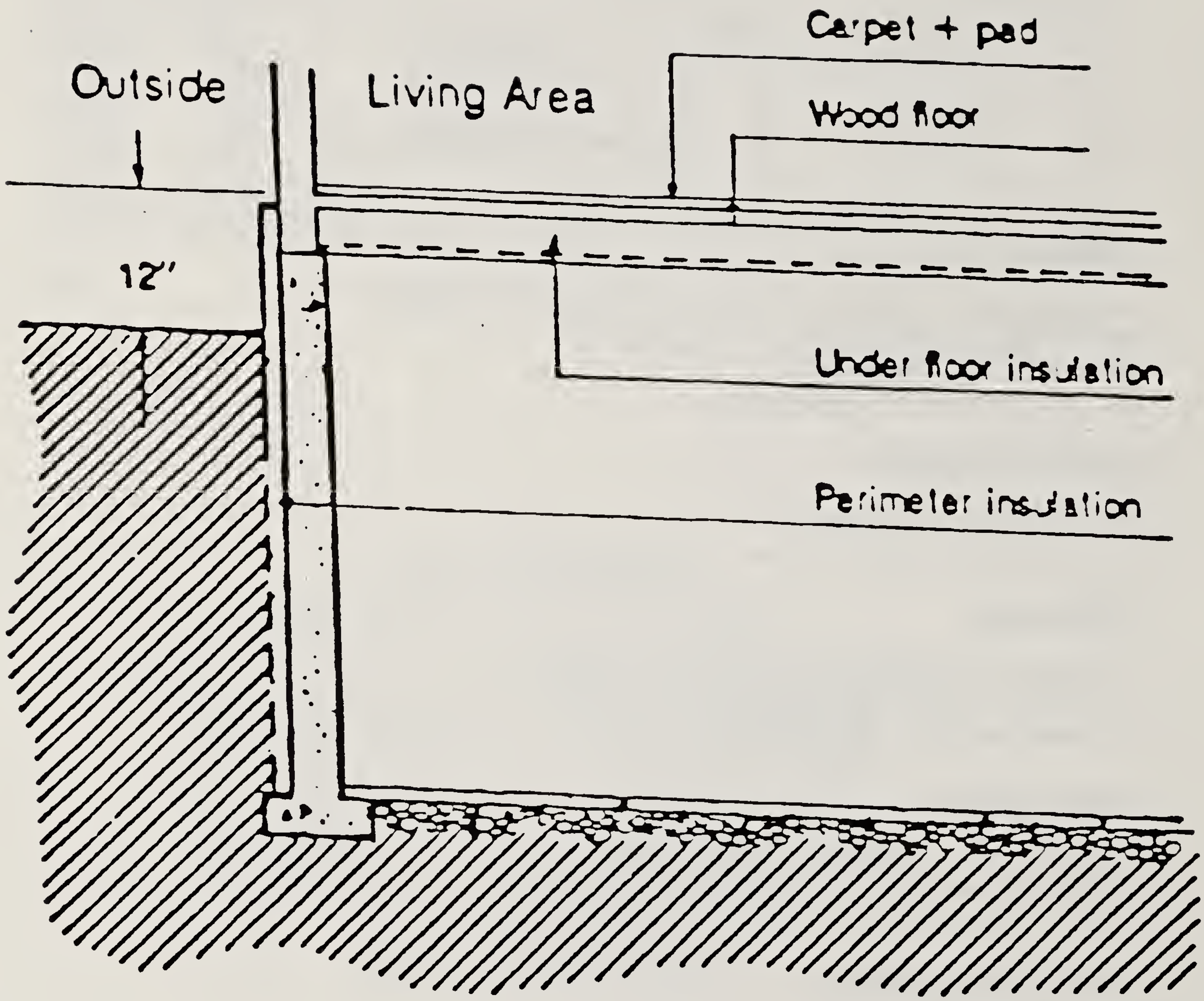


Figure 3

SHALLOW BASEMENT

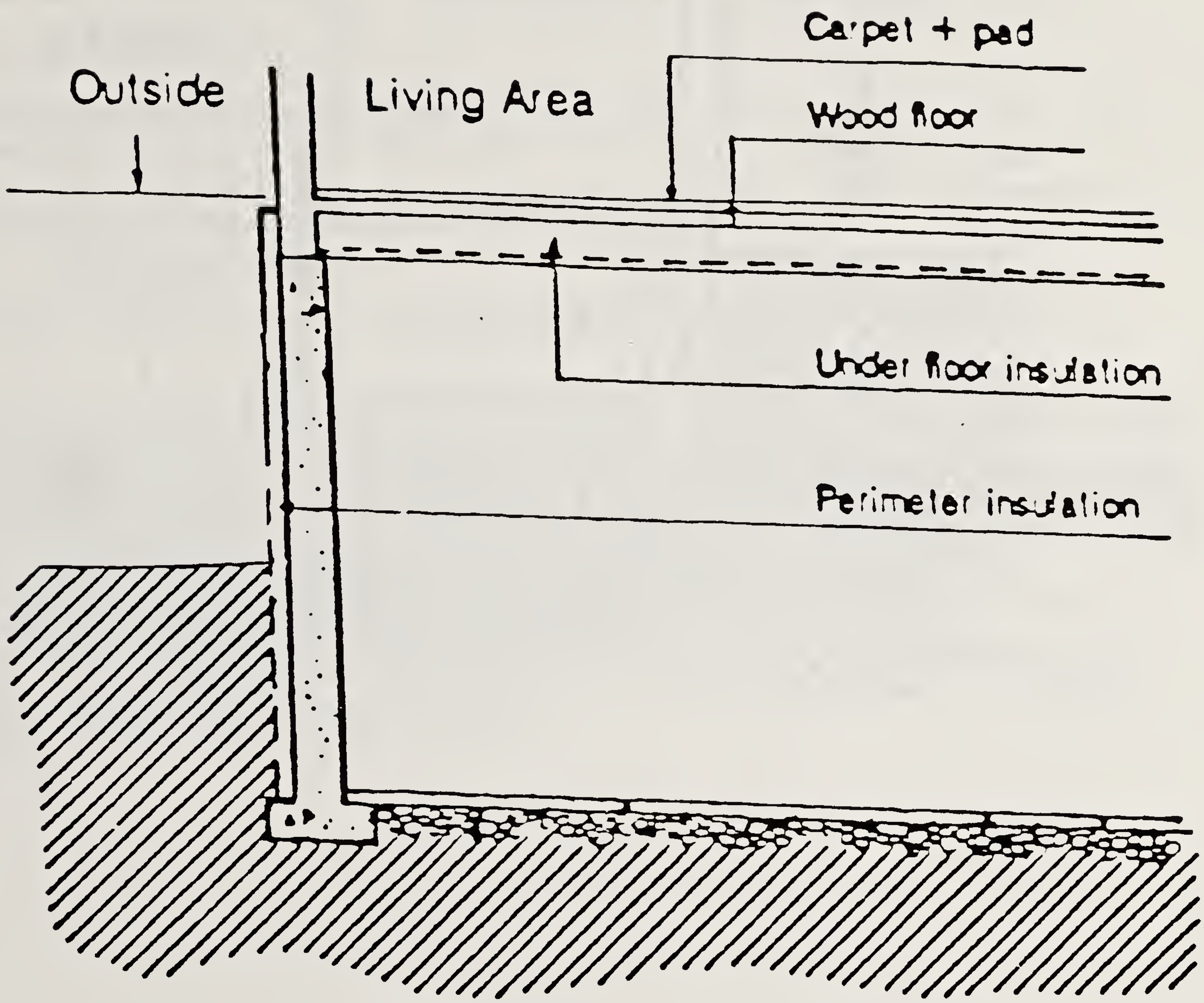


Figure 4

CRAWLSPACE

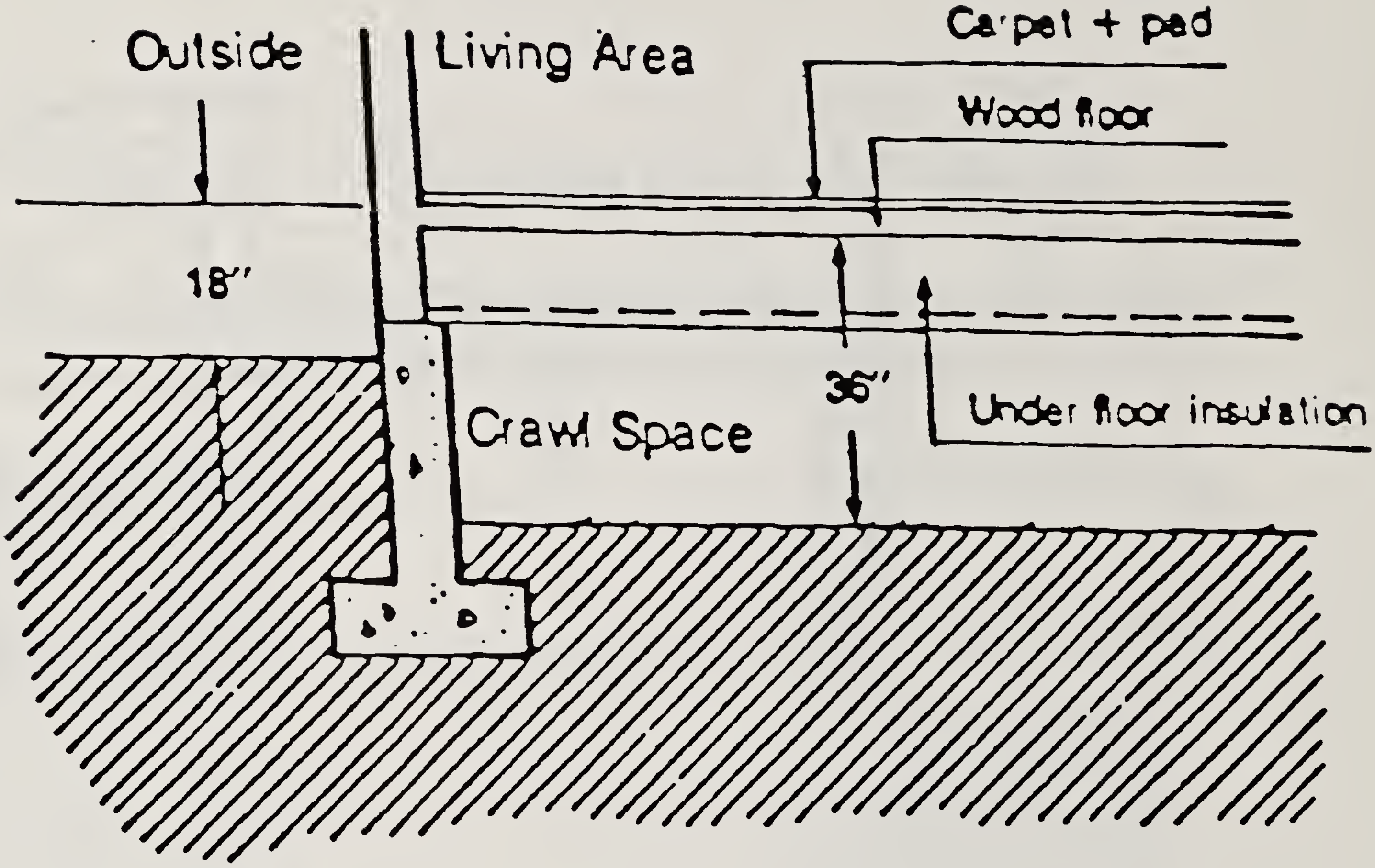
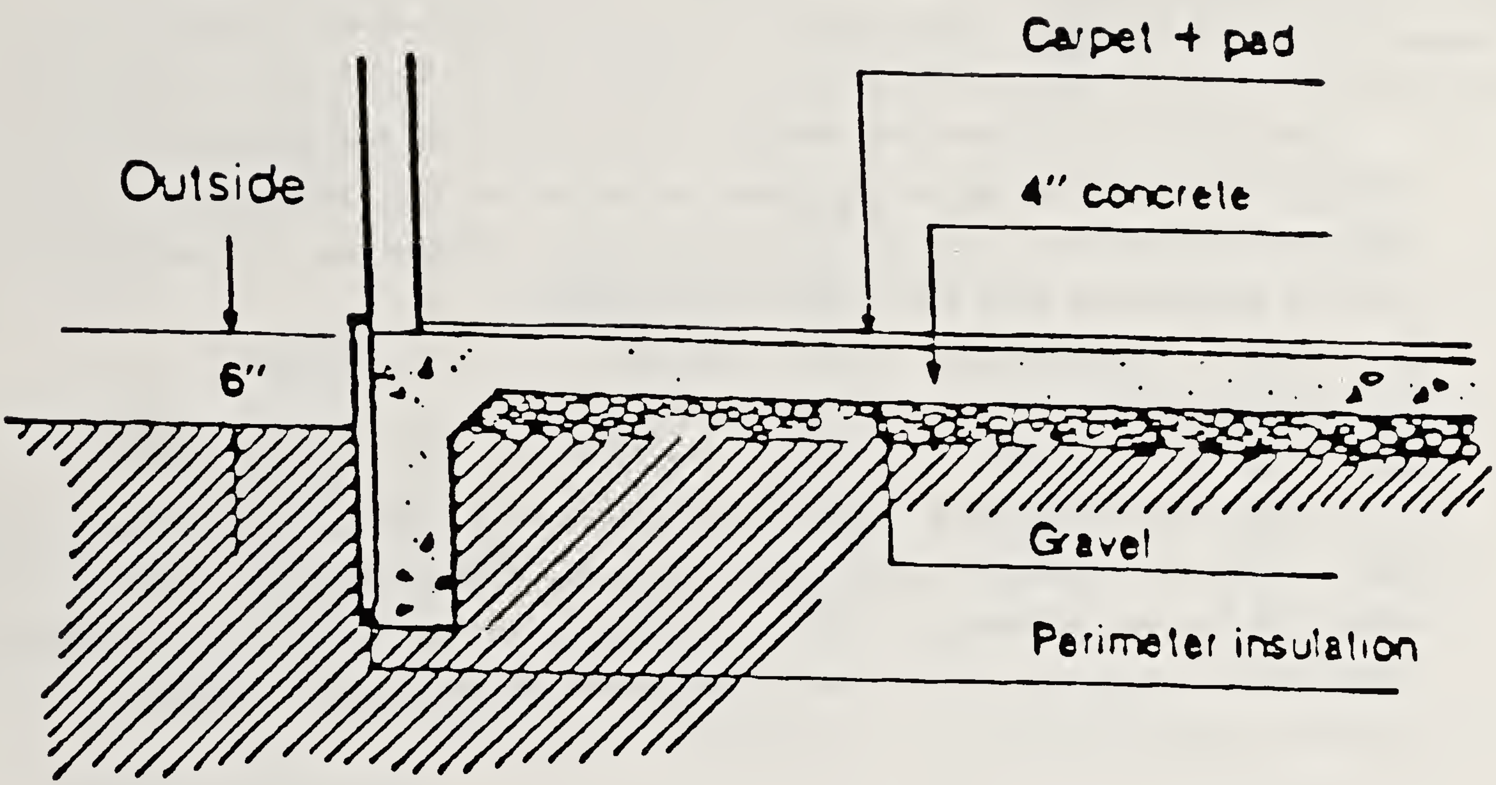


Figure 5

SLAB ON GRADE



$$DD_b(T) = \Sigma \quad N(T_b - \overline{T}_a \quad b \, T_m \quad \sqrt{N}) \qquad [1]$$

where:

N = number of days in month
T_b = base temperature C^o
$\overline{T}_a$ = average monthly outdoor temperature C^o
$T_m = 2.06 - .0337\ T_a$
$b = .34 \exp(-4.7h) - .15 \exp(-7.8h) + zh$
$h = |(T_b - T_a) / (t_m \sqrt{N})|$

$Z = 0$ if $h \geq 0$
$Z = 1$ if $h \leq 0$

The Shipp correlations are based on an interior set temperature of 73° F. Consequently, heating degree days were estimated for this temperature base to compute the F-factors. For Shipp's correlations, themselves, the heating and cooling degree days at a 55° F base are necessary.

Soil Conductivity

Soil conductivity has a large effect on the heat flow in below grade structures, particularly for uninsulated basements where the ground makes up a large part of the effective thermal resistance. Soil conductivity varies due to moisture content, composition, and grain size. Table 3 lists the common thermal conductivities of different types of soil.

Table 3
SOIL THERMAL CONDUCTIVITY

Type	Conductivity (Btu/hr F)
Heavy soil, damp	.75 - 1.10
Heavy soil, dry	.50 - .75
Light, damp soil	.50 - .75
Light, dry soil, clay	.40 - .60

A conductivity of .8 Btu/hr F can be used as a common value for soils. These conductivities agree well with assumptions made by Mitalas, as well as values used by a variety of other researchers. In the Shipp correlations, an apparent soil

conductivity of .86 Btu/hr F was used. These various conductivities can be practically categorized as low, high, and medium conductivities, as in situ values are difficult to determine with accuracy.

Study Sites

Since the study area is in the Pacific Northwest, three representative sites were chosen there -- Portland, Oregon; Missoula, Montana; and Spokane, Washington. Other sites chosen for climatic variation included Columbus, Ohio; Atlanta, Georgia; and Bismarck, North Dakota. Soil, air temperatures, and data for heating degree days and cooling degree days (CDD) were gathered for each site. The site data are given in table 4.

Table 4

BELOW GRADE STUDY SITE DATA

LOCATION	HDD (55ºF)	CDD	HDD (73ºF)	TG	TA
Portland, OR	2,153	1,312	7,431	56	52.6
Missoula, MT	5,006	904	10,674	46	43.7
Columbus, OH	3,400	2,121	7,967	53	51.5
Atlanta, GA	1,310	3,410	4,884	64	60.8
Bismarck, ND	6,264	1,374	11,540	44	41.4
Spokane, WA	4,143	1,295	9,462	50	47.3

TG = mean annual ground temperature
TA = mean annual ambient air temperature

CALCULATION PROCEDURE

Each configuration was modeled for each listed location, using Shipp's correlation methodology for annual heating energy loads. The form of the correlations used was the following:

$$
\begin{aligned}
Q \;=\; & B0 + B1/R + B2 * (HDD/100) + B3 * (CDD/100) + \\
& B4 * (HDD/100)/R + B5 * (CDD/100/R) + \\
& B6 * (HDD/100) * (CDD/100) + B7 * (HDD/100) * R
\end{aligned}
\qquad [2]
$$

where:

- Q = the annual heat loss per linear foot of configuration perimeter (Btu/year)
- R = the R-level of the insulation in the configuration including component R-values and air films
- $B0 \ldots B7$ = regression coefficients empirically determined in the correlation procedure from Shipp (1983)
- CDD = cooling degree days (55°F)
- HDD = heating degree days (55°F)

The only exception to this is the vented crawlspace where Q is given in Btus per square foot of floorspace. The R-value of uninsulated basement, crawlspace, and slab walls was taken as two, which is an average approximation of the R-value of the eight-inch concrete and an interior air film. The exception to this is the wood foundation, which has an uninsulated R-value of approximately three. Once the annual heat loss per linear foot had been developed it is a simple matter to compute the F-factors:

$$F = Q/\int (T_i - T_o)\,\partial t \qquad [3]$$

where:

- Q = the total annual below grade energy loss per linear foot of perimeter
- T_i = interior set temperature
- T_o = hourly outdoor average ambient temperature

so that:

$$F = Q/(HDD*24\ hrs) \qquad [4]$$

where:

- F = the heat loss rate (Btu/hr/°F) per linear foot of the configuration
- HDD = the heating degree days at a 73° F base as determined by equation [2]

The F-factors were determined for the six different sites for the twelve configurations. Since comparison of results from the Mitalas program and the Shipp correlations showed good agreement, the Mitalas method was used for a number of parametric runs to study sensitivity to soil conductivity and wall height. The F-factors for the selected sites were very similar. An average was taken within these groups for each configuration. Standard deviations and the coefficients of variation were tolerably low. The greatest variance was noted in the uninsulated basement types. It should be noted that several runs for warmer sites in the

Southeast showed significant disparities in the F-factors so that no single set of factors could be determined for such sites. Generally, the heat loss rates were lower than those indicated in table 7. The warmest site examined (Miami, Florida) showed coefficients less than half those shown for colder climates. The F-factors are listed by configuration in table 7.

VALIDATION

The Mitalas and DAGT methods were applied to the different basement configurations to determine how their results compared to those based on the modified Shipp correlations. The DAGT method was only estimated for the heated basement case since it is not applicable to other configurations.

For the Mitalas method, average monthly temperatures and the parameters listed in table 4 were used. A complete explanation of the procedure is given in Mitalas (1982). The heat loss was computed on a monthly basis using this procedure excluding the months of May through September. The heat loss during these months does not represent a true heating load and actually is beneficial to interior comfort due to the earth-coupled cooling effect. This exclusion is consistent with the heat load estimation procedure used in Shipp's correlations and also tends to constrain the F-factors to values that best represent winter heat loss rates.

The results of the Mitalas method are given in watts, which are then converted to Btus for the 7-month analysis period. The resulting figure is divided by perimeter length (150 feet) and temperature differential to arrive at the F-factors equivalent to the correlation method.

The decremented average ground temperature method (DAGT) requires that the undisturbed ground temperature be computed. This measure estimates the annual daily ground temperature at depth. It is computed as follows:

$$T = Tm - As\ e^{-z(\pi/365)\ 1/2} \cos[2\pi/365\ (t - t_0 - z/2\ \ 365/\pi\alpha)] \quad [5]$$

where:

Tm = temperature at depth "z" and day "t"
As = annual surface temperature amplitude
t_0 = phase constant to coldest day of year
α = the thermal diffusivity of soil (ft^2/day)

This measure has been calculated for the 15th day of each month for depths of zero, 3, 6, 9, and 12 feet in depth for Missoula, Montana and is shown in figure 6. To calculate heat loss from below grade walls, decrement factors are necessary to show the thermal effect of loss below grade from the heat retention in the soil around the heated structure.

The decrement factors for various soil conductivities and R-levels are given in Akridge and Poulos (1983). Labs (1984c) has shown that the decrement factors for basements can be expressed simply as:

$$FD = \frac{R}{R + \frac{3.7}{k}} \qquad [6]$$

where:

R = R-value of insulation, structure and air filters
K = soil thermal conductivity (Btu/hr/F°)

Once the decrement factors are determined, the heat loss is estimated by:

$$L = FD * (T_i - T_s) * 1/R \qquad [7]$$

where:

L = heat loss in Btu/hr/ft^2
FD = decrement factor for insulation value and soil conductivity
T_i = temperature inside the heated, below grade space
T_s = undisturbed soil temperature at the depth of the wall
R = R-value of insulation, structure and air film

To use the method a procedure must be used to estimate basement floor losses. In lieu of an established approach, the floor losses were determined from undisturbed soil temperature at a depth of one-fourth of the basement width plus the floor depth (a surrogate shape factor).

Both the Mitalas and DAGT methodologies were used to model the heated basement case in Missoula, Montana. A comparison of the Mitalas and DAGT heat loss predictions by month is shown in figure 7. There is good agreement during the winter months but a significant disparity during the summer. Closer inspection of heat loss by component shows the disparity exists in the larger wall heat losses

Figure 6

UNDISTURBED GROUND TEMPERATURE

MISSOULA, MONTANA

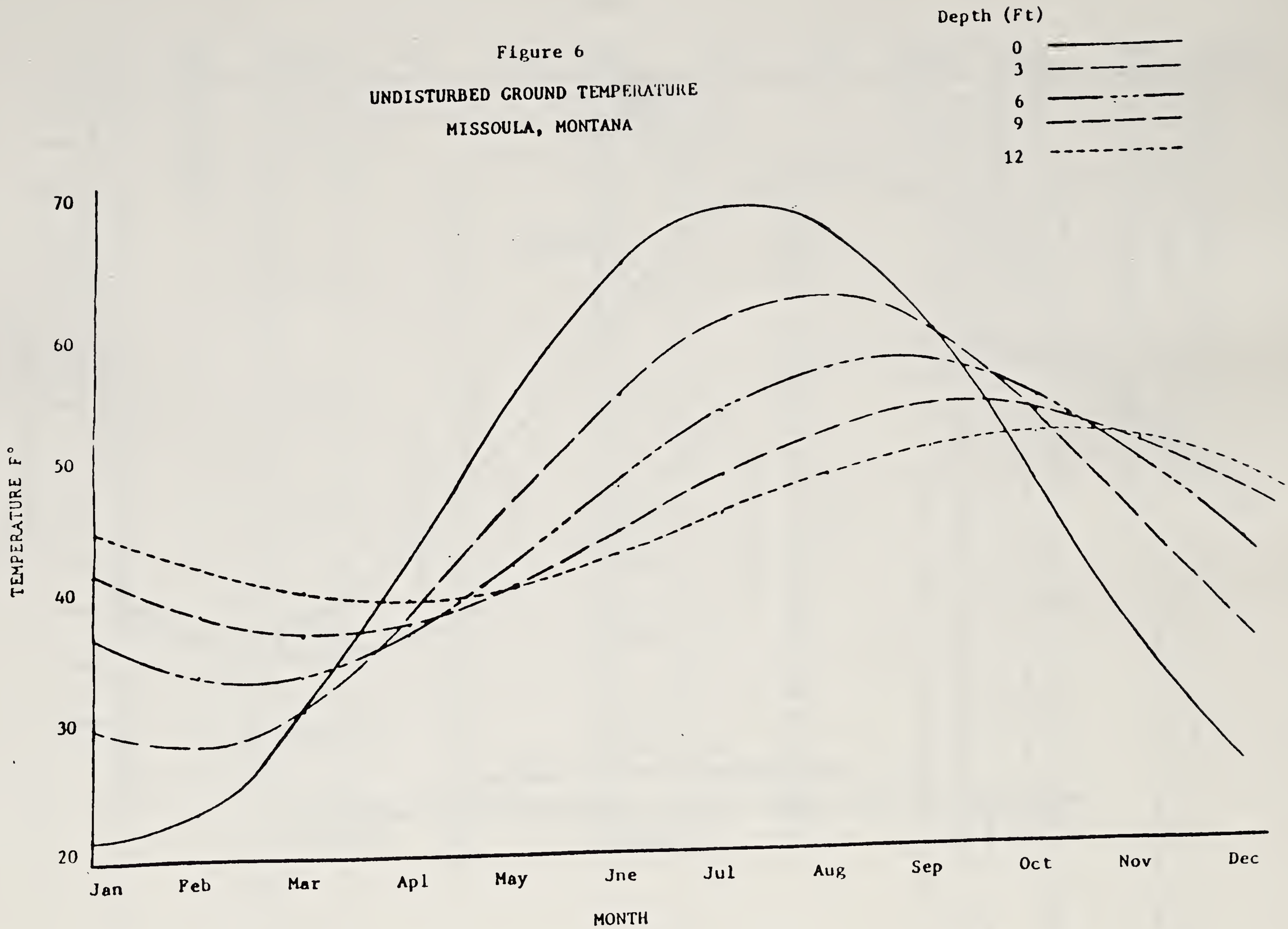
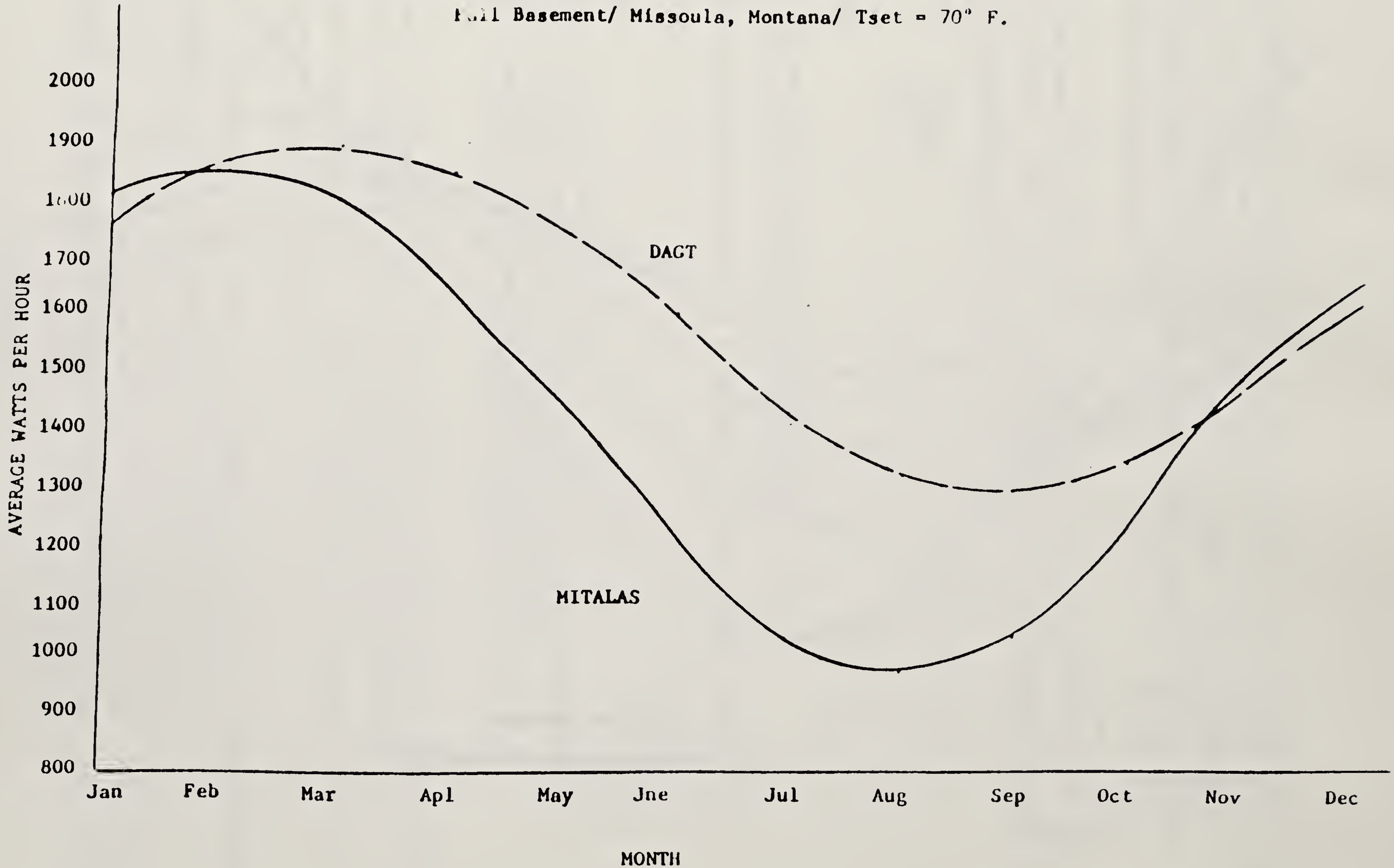


Figure 7

COMPARISON OF PREDICTED MONTHLY HEAT LOAD USING MITALAS AND DAGT METHODS

Full Basement/ Missoula, Montana/ Tset = 70° F.



predicted by the DAGT method during summer months. This disparity had little effect on this study, however, since the months of non-agreement are the ones where the heat loss is not counted as actual heat load.

Table 5 shows the F-factors determined from each method for the heated basement prototype in Missoula. Table 6 shows the F-factors as determined by Shipp's correlations and the Mitalas method for slab floors in Missoula. Agreement of the two methods with the modified F-factors from the Shipp correlations is good. The coefficient of variation in results from the three methods was typically about nine percent.

Table 5

COMPARISON OF F-VALUES FROM SHIPP, MITALAS AND DAGT METHODS

	Actual R-value						
Method	2	5	10	15	20	25	30
Correlation	1.55	1.09	.90	.80	.73	.66	.60
Mitalas	1.74	1.25	.96	.84	.78	.74	.72
DAGT	1.62	1.19	.92	.81	.74	.69	.66

Fully below grade basement, full wall insulation, Missoula, MT, 70° F set temperature.

Table 6

F-VALUES FROM SHIPP CORRELATION AND MITALAS METHOD FOR SLAB FLOORS

	Actual R-value						
Method	2	5	10	15	20	25	30
Correlation	.47	.44	.42	.41	.40	.38	.37
Mitalas	.47	.45	.43	.41	.40	.39	.39

4-foot horizontal perimeter slab insulation, Mitalas configuration #62, Missoula, MT

F-FACTOR TABLES

Table 7 presents the F-factors used in the method. It gives values for each R-level and configuration type.

Table 7

F-FACTORS FOR THE METHOD
(>2,500 HDD @ 65°F)

Configuration	Actual R-value 2	5	10	15	20	25	30
BA	1.54	1.08	.88	.78	.71	.65	.59
BB	1.62	1.38	1.24	1.17	1.12	1.08	1.04
BC	2.30	1.38	1.03	.88	.78	.70	63
BE	.69	.56	.49	.46	.42	.39	.36
BG	.87	.67	.57	.53	.48	.44	.40
BI	1.02	.84	.63	.51	.41	.33	.25
CA	.93	.64	.53	.49	.46	.44	.43
CG	.91	.61	.49	.42	.37	.32	.28
SA	.50	.47	.46	.45	.44	.43	.42
SB	.50	.44	.42	.41	.40	.38	.37
SD	.51	.44	.41	.39	.37	.36	.34
F*	.120	.069	.049	.040	.034	.029	.025

BA = heated basement, full wall insulation
BB = heated basement, half wall insulation
BC = shallow basement, full wall insulation
BE = unheated basement, full wall insulation
BG = unheated shallow basement, full wall insulation
BI = heated basement, all-weather wood foundation, full wall insulation
CA = crawlspace with wall insulation
CG = crawlspace with all weather wood foundation, wall insulation
SA = slab floor, 2 feet horizontal insulation
SB = slab floor, 4 feet horizontal insulation
SD = slab floor, 4 feet vertical insulation
F = insulated floor over unconditioned space (crawlspace or unheated basement)
* = U-values, Btu/ft^{2}F°

DISCUSSION OF RESULTS

The F-factors are fairly consistent for temperature climates. Little variation in the F-factors is evidenced for climates with more than 2,500 HDD at a 65° base. Warmer climates have much lower heat loss rates per lineal foot.

For both climates the slab on grade type has the lowest consumption at various insulation levels. Vertical insulation performed marginally better than horizontal installations. Diminishing returns become pronounced for insulation levels greater than about R-20.

Results show shallow basements to be the most consumptive configuration, followed by fully heated basements. Half wall insulation was found to be an inferior method for heat loss control. Typically the unheated basement type all-weather wood foundation (AWWF) basements have the best thermal performance.

The crawlspace study yielded interesting results. Generally, an insulated concrete crawlspace wall uses a third more energy annually than a vented crawlspace under an insulated floor. However, an AWWF insulated crawlspace wall is more efficient than other crawlspace types due to its lower conductance so that thermal bridging through the wall structure from the heated area above is minimized.

The Shipp correlations do not address three-dimensional heat flow from corner effects in the thermal conductance model. Consequently, losses are understated by about 10% in the uninsulated case (see Swinton and Platts 1981). An adjustment is made in the calculations for F-factors for uninsulated basements.

As with all correlation methods, the chief weakness lies in application to R-levels and other off-reference case characteristics not listed in the tables. A series of simple interpolation procedures will be presented to facilitate practical use of modified F-factor analysis. This will allow the method to be applied in a general fashion.

HOW TO USE THE METHOD

The modified F-factor method for determining below grade heat loss can be described in seven steps.

1. Determine the Heating Degree Days at the Set Point Temperature Base: This can be calculated from equation 1 or from a reference such as the *Passive Solar Design Handbook* for a given location.

2. Determine the House Configuration in the Table: In table 7 find the configuration most like the one you are considering. It is possible that more than one configuration will be applicable (such as a house that has a partial slab floor and crawlspace combination).

3. Determine the F-factor: Find the F-factor from the table for the R-level of insulation that is being considered. If there are different insulation levels on different sections of the configuration, take an area weighted average. Be sure to add an R-value equivalent for the wall composition and air films. Add an R-value of .68 as allowance for an interior air film. Concrete walls or floors have an R-value of .2 per inch thickness. All weather wood foundation walls have an R-value of 2.5. (Example: An 8" concrete wall would have an inherent insulation value of 2.3 from the concrete and air film.) Often the R-level determined will not be shown in the tables. The F-factor can be estimated using linear interpolation:

$$F = F1 - \frac{(F1 - F2)}{(R2 - R1)} * (R2 - R1) \qquad [8]$$

where:

F = the interpolated F-factor
F1 = the F-factor for the lower value in the table
F2 = the F-factor for the upper level in the table
R = the R-level for the configuration
R1 = the R-level of the lower value in the table
R2 = the R-level of the upper value in the table

If a basement is uninsulated, the F-factor interpolated should be multiplied by 1.1 to account for corner effects. If you would like to vary internal gain or air infiltration assumptions, see appendix A.

4. Adjust for Soil Conductivity: If the conductivity of the soil in your location is different from the reference value (.80 Btu/hr/ft) then find the soil conductivity adjustment (SCA) ratio.

	Soil Conductivity		
	Low	Med	High
Btu/hr/ft	(<.7)	(.7-.9)	(>.9)
SCA =	.8	1.0	1.2

No soil conductivity adjustment should be used with AWWF crawlspace floor types.

5. Adjust for Basement Wall Height: If the configuration is a basement and the wall height (WH) is different from the reference value (8 feet), then calculate the adjustment factor:

WHA = 1+(WH-8)*.04 [9]

6. Calculate Modified F-factor and Below Grade 'UA': Multiply the F-factor found in the interpolation procedure by each of the adjustment factors. Then multiply the resulting modified F-factor by the perimeter length to arrive at the below grade "UA." If you have a mixed floor system then you will need to repeat steps 1-5 for each floor type and then multiply the appropriate F-factor times the perimeter length for each:

F-factor = F * SCA * WHA [10]

UA = F * perimeter length [11]

7. Estimate Annual Heat Loss: Multiply the below grade UA times the heating degree days and multiply by 24 hours per day. Annual heat loss is given in Btus per year.

Q = UA * HDD (F.) * 24 hours

DETERMINING DESIGN HEAT LOSS RATES

The F-factor can be used to estimate design heat loss rates for the sizing of auxiliary heating equipment.

Kusuda, Bean, and Mitalas (1984) have used the Mitalas algorithm to estimate the F-factors that relate to design heat loss rates. The results from that study closely follow results of this investigation. The researchers found that the design heat loss rates can be related to heating degree days and that little regional variation is observed in areas with 3,000 or more heating degree days (65^{o} base). Furthermore, close examination of their results indicates that design heat loss rates for January through February can be simply estimated by the modified F-factor approach.

The auxiliary heating equipment size necessary to supply the design heat loss from the below grade configuration is:

$$DHL = F * P * (T_i - T_{o,d}) \qquad [12]$$

where:

DHL = design heat loss rate of below grade configuration (Btu/hr/F)
F = F-factor from Table 7
P = perimeter length
T_i = interior temperature (ex. $70^{o}F$ for heated areas)
$T_{o,d}$ = 97 1/2% design temperature (ASHRAE 1981)

EXAMPLES OF THE SIMPLIFIED METHOD

Example 1

A fully below grade heated basement is to be built in Ottawa, Ontario. The basement will have dimensions of 27.9 x 30 x 7 feet. The average area weighted R-level of the walls is to be R-9.2 with full wall insulation. The configuration 'BA' in table 7 best fits the description.

The basement will be maintained at a 70 degree temperature. Ottawa has 10,086 heating degree days (HDD) at a $70^{o}F$ base. There are 8,834 HDD ($70^{o}F$) during the winter season (October through April). The soil is a leda clay with an apparent conductivity of .52 Btu/hr/ft.

The F-factor is interpolated from table 7. An R-5 wall has a F-factor of 1.08, an R-10 wall a value of .88:

$$F = 1.08 - \frac{(1.08 - .88)}{(10 - 5)} * (9.2 - 5)$$

$$F = .91$$

The soil conductivity adjustment ratio is determined:

SCA = .52 Btu/hr/ft (low conductivity soil)
SCA = .8

The basement wall is 7 feet high, as opposed to 8 feet in the reference case.

Calculate the wall height adjustment ratio:

WHA = 1 + (7-8)*.04
WHA = .96

The final modified F-factor is estimated:

F = .91 * .8 * .96

F = .70

The below grade UA is:

UA = 115.8 ft * .70

UA = 81.06

The winter season (October through April) heat loss is:

Winter heat loss = 81.06 * 8,834 * 24 hrs

= 17,186,017 Btus

This is the same example as presented in Mitalas' analysis (1983). During the months considered (October to April inclusive), the heat loss estimated in that procedure was 16,171,114 Btus. The results of the two methods agree within about six percent. Greater accuracy is available by making the adjustments detailed in appendix A.

The 97 1/2 percent design temperature in Ottawa is $-13^{o}F$. The design heat loss rate for the basement is:

L = 115.8 * .70 * (70- -13)
= 6,728 Btu/hr

About 2,000 watts of baseboard electric resistance heat would be necessary to supply the design heat load.

A More Complex Example

A superinsulated, passive solar house is being built in Topeka, Kansas. The designer wants a slab for thermal mass in the sunspace, a small unheated basement for storage, and the rest of the perimeter consisting of an all-weather wood foundation crawlspace. The house is 1,500 square feet with a 165-foot perimeter. The owner will accept temperature swings from the solar component in which the average internal temperature maintained will be 65 degrees. The slab will be 20 x 30 feet with two of the edges exposed to the exterior. The unheated below grade basement will be 25 x 25 x 7 feet with two edges exposed to the exterior as well. The slab will be given horizontal R-10 insulation under its perimeter into a distance of two feet. The basement will have R-11 fiberglass wall insulation on its full length and the crawlspace wall will have R-19 insulation.

1. Find Heating Degree Days at a 65-Degree Base: 5,243 in Topeka, Kansas. For the heating season of October through April there are 5,057 HDD.

2. Calculate the Exposed Edges of Each Type in a Mixed System:

   A. Slab = 50 feet
   B. Basement = 50 feet
   C. Crawlspace = 65 feet

3. Determine the System Types:

   A. Slab = SA
   B. Basement = BE
   C. Crawlspace = CG

3. Add Component R-values and Determine the F-factor for Each System: Interpolation:

	Type	Actual R	F-factor
A.	Slab	12.3	.42
B.	Basement	13.3	.47
C.	Crawlspace	22.0	.35

4. Adjust for Soil Conductivity: The soil is of a normal type, so no adjustment is necessary.

5. Adjust for Basement Wall Height: This adjustment only applies to the basement F-factor estimate:

   WHA = 1+(7-8)*.04

   WHA = .96

6. Compute Modified F-factors for Each Configuration:

A.	Slab		= .42
B.	Basement	.47 * .96	= .45
C.	Crawlspace		= .35

7. Estimate Total Below Grade UA: Multiply F-factors for each type by the exposed perimeter length associated with each:

A.	Slab	= .42 * 50 ft	= 21.00
B.	Basement	= .44 * 50 ft	= 22.50
C.	Crawlspace	= .35 * 65 ft	= 22.75
	Total UA		66.25

8. Estimate the Annual Heat Energy Load from the Below Grade Portion of the House:

   Annual heat load = 65.75 * 5,243 * 24 hrs
   = 8,273,454 Btus

   Winter heat load = 65.75 * 5,057 * 24 hrs
   = 7,979,946 Btus

CONCLUSIONS

A simple modified F-factor method has been presented to determine annual heat losses by using twelve different earth coupled configurations commonly encountered in the shelter industry. This method is based on the correlations developed by Shipp (1983). Agreement between the results of modified F-factor and two contemporary analytic methods has been excellent. The decremented average ground temperature method (Akridge and Poulos 1983) and the method of Mitalas (1982) agree with the correlations to within about ten percent for basement heat load determination. For a more rigorous approach for determination of daily or monthly heating loads either of the two described methods are recommended. However, modified F-factor analysis does allow accurate determination of annual space heating loads and design heat loads from basements and other floor types on a hand calculator. Accuracy for heat loss determination should be within 20 percent of a more detailed analysis. The method is not applicable to cooling load determination.

The modified F-factor method can handle different heating set points, heating degree day bases and soil conductivities. It is possible to analyze mixed floor configurations or non-reference basement wall sizes. The technique should be helpful for determination of heat loss coefficients for use in residential steady state heat loss calculations such as the Los Alamos load collector ratio method.

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APPENDIX A

ADJUSTING FOR AIR INFILTRATION AND INTERNAL GAINS

Two approximations in the simplified method are examined in greater detail in this section. This allows corrections to be calculated for off reference valves of air infiltration and internal heat gains in the thermal analysis of basements.

Air Infiltration

The Shipp correlations make implicit assumptions on below grade air infiltration rates (Shipp 1984). Basically, it was assumed that only half the volume of a basement would be eligible for air exchange at a rate similar to the above grade area. This results in typical effective infiltration rates of .15 ACH for below grade areas given the "tight" energy efficient design assumed. This estimate is consistent with estimates by Stensul (1984) and Shaw (1984) where basement air infiltration rates were estimated at 33 percent and 40 percent of above grade valves, respectively. Stack effects are small in basements and most infiltration will come from the band joist and exposed windows above grade. A method is given to estimate effects of off reference valves. However, since below grade infiltration is difficult to determine, adjustments are not recommended unless empirical data such as a blower door test is available.

Internal Heat Gains

It is assumed in the correlations that internal heat gains are present in basements so that an average of 3.0 kwh/day (10,240 Btus) of free heat is released into the below grade space. This would represent the typical standby losses of an insulated hot water heater or losses from duct work in the unheated case. If such losses are not present, then they must be added to the annual heat energy demand of the basement cases. Internal gains must be subtracted from the Mitalas or DAGT estimates if they are present.

1. Air Infiltration Adjustment

   If air infiltration is different from the reference value (.15ACH), then calculate change in 'UA':

$$UA_I = UA + V * .018 + ADR * (ACH - .15) \qquad [13]$$

where:

ACH = the effective air change rate for the basement
V = volume of basement
ADR = air density ratio [ADR= 1+ -.032 (Elevation ft/1000)]
UA = loss coefficient for basement calculated in step 6

2. <u>Adjust for Internal Heat Gains</u>
If the rate of internal heat gains differs from the reference value (3.0 kwh/day), make the following adjustment:

$$Q' = Q = DY * \Delta INT \qquad [14]$$

where:

Q' = annual or seasonal heat load from basement as modified by internal gains
DY = days in analysis period
Δ INT = difference of internal gains from reference value (10,240 Btu/day)

It is recommended that DY not exceed the heating season (<270 days) since summertime internal gains are not useful in offsetting heating loads for the basement.

<u>Example</u>:

The analysis in example 1 is re-examined.

The Mitalas study did not include assumptions on infiltration or internal heat gain. To make the results comparable, both infiltration losses and the internal gains should be included in that example.

1. <u>Adjust for Air Infiltration</u>

The basement has a volume of 5,859 cubic feet. An air change rate of .15 ACH is assumed. Ottawa, Ontario is at an altitude of 377 feet (ADR = .99).

$UA' = 0 + 5,859 * .018 * .99 * .15$

The additional infiltration load for the winter season is then:

$L_I = 15.66 * 8,834 * 24$ hrs

$Q = 16,174,114 + 3,320,171$

$Q = 19,494,285$ Btus

2. <u>Adjust for Internal Heat Gains</u>

The 3.0 kwh/day internal heat gain rate assumed in the example must be subtracted from the estimated load. There are 213 days in the indicated heating season (October through April).

$$Q' = 19{,}494{,}285 - 213 * 10{,}240$$

$$= 17{,}313{,}165 \text{ Btus}$$

The results of the two methods now agree within one percent.

APPENDIX B

OPTIMIZING BELOW GRADE INSULATION LEVELS

Analytic solutions for optimal conservation levels below grade are compromised by the complexity of foundation heat loss. Ideally, an optimal level of insulation for a house would result in equivalent heat loss from each areal segment of the structure (Claesson and Eftring 1980). Practically, the losses will be different because the structure and insulation required to reduce heat loss have different costs. The following section will briefly describe a method to determine approximate optimal levels of insulation for the different configuration types. We will take an average case, using a mid-western climate for the analysis.

Balance Point Temperature

Common analytical practice for the above grade portion of buildings is to equate the auxiliary heating load based on the "balance point temperature," in effect discounting heat losses that are made up for by intrinsic internal heat gains. These rates of internal heat release are typically 2,000 - 3,000 Btus per hour in most homes. The balance point in such a case is typically the thermostat set point temperature minus the internal heat gain rate divided by the building thermal loss coefficient (Btu/hr/F) or:

$$T_{bal} = T_{set} - Q_{int}/ \quad UA \qquad [15]$$

where:

T_{bal} = balance point temperature (F)
T_{set} = thermostat set point temperature (F)
Q_{int} = internal heat gain rate (Btu/hr)
UA = building heat loss coefficient (Btu/hr)

For typically sized existing homes, the above grade thermal loss coefficient is approximately 400 - 600 Btu/hr/F. Assuming an average 65 degree setpoint, this implies a balance point for existing homes on the order of 60 degrees (ignoring solar gains). However, new construction tends to be better insulated, resulting in typical loss coefficients for houses of about 250 - 350 Btu/hr/F. Therefore the balance point temperature in such homes is only 53 - 59 degrees. For the purposes

of this study a 55 degree balance point was chosen. This is conservative since typical solar gains tend to further depress the effective building balance temperature.

Above Grade Optimization

It is possible to determine the optimal insulation level of above grade surfaces through the following calculation. This includes exposed basement walls.

$$LCE = \frac{PV * FC * HDD * 24\ hrs}{10^6} \qquad [16]$$

$$R_o = \sqrt{(LCE/MCR)} \qquad [17]$$

where:

LCE = lifecycle cost of a Btu/hr/F of energy savings
R_o = optimal R-level
PV = present value factor for future fuel costs
FC = cost of a million Btus of heat (includes furnace inefficiency)
HDD = heating degree days at the house balance temperature
MCR = marginal cost of an 'R' of insulation

and:

$$PV = \frac{(1+e)}{(d-e)} \left[1 - \left(\frac{1+e}{1+d}\right)^N\right] \qquad [18]$$

where:

d = discount rate/opportunity cost of capital (real or nominal)
e = expected fuel price escalation rate (real or nominal)
N = the period of the analysis (years)

The discount rate used should be the builder's opportunity cost of capital if an investment, or the interest rate at which the project is financed. This is modified by the consumer's tax rate since interest earned is taxable, and interest paid on a loan is deductible. The effective discount rate is then:

$$d = i\ (1-t) \qquad [19]$$

where:

i = interest earned or paid on an investment
t = the marginal state and federal tax bracket of the consumer

In the analysis, we assume that the owner will finance the thermal improvements to the new house along with the mortgage for the house. The interest rate is 13 percent (.13) over the period and his tax bracket is 30 percent (.30). The effective discount rate for the investments is then 9.1 percent (.091).

The marginal cost of insulation is:

$$MCR = (C2 - C1)/(R2 - R1) \qquad [20]$$

where:

MCR = marginal cost of an 'R' of insulation
C1 = cost of a square foot of wall section 'one'
C2 = cost of a square foot of wall section 'two'
R1 = the R-level of wall section 'one'
R2 = the R-level of wall section 'two'

<u>Example</u>

A designer wishes to build an energy efficient house in Topeka, Kansas. He determines from equation (15), that a 55 degree heating balance point will be appropriate to the analysis. There are 3,175 heating degree days at this location. The house uses electricity, which costs six cents per kilowatt hour. The heat content of a kilowatt of electricity is 3,413 Btus, so a million Btus costs $17.58. The designer is financing the project at an interest rate of 13 percent and we believe, for analysis, that nominal fuel prices will increase at about 6 percent per year over the thirty-year period. Costing out different wall sections, an R-20 wall with 2 x 6 construction wall costs about $3.00 per square foot and R-40 wall with double 2 x 4 construction costs $4.00 a square foot. Calculating the present value factor, we estimate that the value of future savings are 19.79 times the first year savings. Using equation [20] the marginal cost of insulation is $.05 per 'R'. The optimal level of wall insulation is then:

$$LCE = 19.79 * 17.58 * 3{,}175 * 24/10^6$$

$$LCE = 26.51$$

$$R_o = \sqrt{(26.51/.05)}$$

$$R_o = 23.0$$

An R-level of 23 is justified for the exposed walls.

Below Grade Optimization

The optimal UA of any building component, including those below grade, can be determined using the inverse form of equation [17]:

$$UA_o = \sqrt{MCR/LCE} \qquad [21]$$

The marginal cost for conservation is defined in this case as:

$$MCR = (C2-C1) / (1/UA_2 - 1/UA_1) \qquad [22]$$

where:

C1, UA_1 = the cost and UA of the less insulated option
C2, UA_2 = the cost and UA of the better insulated option

Once the optimal below grade 'UA' is determined, the optimal F-factor can be found by dividing by the perimeter length:

$$F_o = UA_o /Pt \qquad [23]$$

The R-level associated with the indicated F-factor can be interpolated from table 7.

Heated Basement

In our example the designer has received estimates from the builder on the costs of finishing and insulating the basement to different levels with fiberglass insulation hung over interior framing. It will cost about $1,000 to insulate the heated basement to R-11 and $1,600 to insulate the basement to a maximum practical level of R-30. Examining table 7, the designer finds the F-factor for configuration 'BA' for the R-11 case (R-13.3) to be .81, and .59 when insulated to R-30. Given the 150-foot perimeter, this equates to a 'UA' of 121.5 in the R-11 case and 88.5 when insulated to R-30. The designer calculates MCR:

$$MCR = (\$1,700 - 1,000) / (1/88.5 - 1/121.5)$$

$$MCR = 228,088.6$$

Calculating the optimal below grade 'UA':

$$UA_o = \sqrt{228,088.6/26.51}$$
$$UA_o = 92.76$$

The optimal F-factor is 'UA' divided by the perimeter length:

$$F_o = 92.76/150$$
$$F_o = .62$$

Looking at the F-factor table, we find that F = .62 occurs at an R-value of about 28. The designer decides on an R-25 batt installed between the interior framing (actual R value of 27.3).

For an exterior application of insulation in the same case the results are quite different because of the larger costs of polystyrene insulation that can withstand such weathering conditions. Our designer finds that extruded polystyrene costs about $5 per 2 x 8 foot sheet. He estimates that one inch of this insulation on the exterior wall (R-5.5) will cost $500 installed and four inches will cost $1,500. In this case the actual R-values of the two options are R-7.7 for one inch and R-24.2 for four inches. From table 7 for configureation 'BA', this corresponds to F-factors of .972 and .660, respectively. The 'UA' values are then 145.8 and 99.0 Btu/hr F. The marginal cost per R (MCR) is:

$$MCR = (\$1,500 - \$500) / (1/99.0 - 1/145.8)$$
$$MCR = \$308,423.08$$

The optimal UA is then:

$$UA_o = 308,423.08 / 26.51$$
$$UA_o = 107.86 \text{ Btu/hr F.}$$

The corresponding F-value is:

$$F_o = 107.86 / 150 \text{ ft.}$$
$$F_o = .72$$

Interpolating from table 7, an F-value of .72 occurs at an actual R-value of about 19.3. This corresponds to an insulation value of about R-17. The designer opts for 3 inches of polystyrene (R-16.5). We see that the optimal amount of insulation for the heated basement is quite sensitive to the cost of the material involved.

Unheated Basement

Continuing our example, the builder wishes to find the optimal insulation level for an unheated basement wall. The costs of the job are the same as in the heated case, although the thermal returns from the improvement are quite different. Looking at configuration 'BE' we interpolate to find an F-value of .47 when R-11 (13.3), and .36 when insulated to R-30 corresponding to UA coefficients of 70.5 and 54, respectively. The marginal cost per R is:

$$MCR = (\$1{,}700 - 1{,}000 / (1/54 - 1/70.5)$$
$$MCR = 161{,}509.1$$

The optimal UA is:

$$UA_o = \sqrt{161{,}509.1 / 26.51}$$
$$UA_o = 78.05$$

The optimal F-value is:

$$F_o = 78.05/150$$
$$F_o = .52$$

Interpolating from table 7 we find that F = .52 occurs at an R-value of about 8. Based on this information, and the possibility that the basement may be finished out at some point and heated, the designer opts for an R-11 batt on the basement walls.

Unvented Crawlspace

The cost to insulate an unvented crawlspace wall to R-30 with extruded polystrene is estimated at $1,200 versus $200 to insulate it to R-5 (actual R = 7.3). The applicable F-factors for type 'CA' are .59 for R-5 and .43 for R-30.

$$MCR = (\$1{,}200 - 200)/ (1/64.5 - 1/88.5)$$
$$MCR = 237{,}843.8$$
$$UA_o = \sqrt{237{,}843.8/26.51}$$
$$UA_o = 94.72$$
$$F_o = .63$$

An F-value of .63 corresponds to an R-value of about 6. It would pay to install the lesser amount of insulation to the wall. The designer decides on one inch of polystyrene (nominal R-value = 5).

Insulated Floor over Unfinished Basement or Vented Crawlspace

This type represented by configuration 'F' in table 7. The F-factors are given in terms of Btu/square foot, rather than for the perimeter length. It is estimated to cost $600 to insulate the 1,350-square-foot floor to R-11 with fiberglass and $1,100 to R-30.

$$MCR = (\$1,100 - 600)/ (1/33.75 - 1/63.45)$$

$$MCR = 36,051.1$$

$$UA_O = \sqrt{36,051.1/26.51}$$

$$UA_O = 36.88$$

$$F_O = 36.88/1350$$

$$F_O = .027$$

The F-value of .027 corresponds to an R-value of about R-27. The designer opts for an R-25 batt installed between the floor joists.

Slab on Grade

Analysis of economic thickness of slab on grade insulation is a little tricky. Since the incremental thermal returns are quite low, we must concentrate on lower insulation levels in the optimization. The non-linearity of the insulation performance makes this approach practical. Assuming the use of 4 feet of vertically installed polystyrene, we estimate that it will cost $400 to insulate to a level of R-10 (actual R = 12.3). The F-factor for the uninsulated situation is .51 and .40 for R-10.

$$MCR = (\$400 - 0) / (1/60 - 1/76.5)$$

$$MCR = 111,272.7$$

$$UA_O = \sqrt{111,272.7/26.51}$$

$$UA_O = 64.79$$

$$F_O = .43$$

The indicated F-value corresponds to an actual R-value of about 6. The designer selects one inch of extruded polystrene for the insulation.

Discussion

The method illustrated here is reasonably accurate as long as the designer is careful about the insulation levels selected for study. Because the method assumes both linear cost and performance, the results are subject to error from cases with a wide range in insulation levels particularly when the range includes an uninsulated case. Higher fuel costs or colder climates will lead to indicated F-values that are lower than those shown in table 7 for heated basements. In such cases the optimization cannot be interpreted beyond the limits of the F-values.

It is possible to directly determine the optimum below grade R-levels in an iterative process. F-factors are computed for each R-level from 0 to 30 and cost estimates are made for each level. The lifecycle cost of that configuration is then:

$$LCC = C1 + F * Pt * HDD * 24hrs * PV \qquad [24]$$

where:

LCC = lifecycle cost of the option
C1 = the initial cost of the insulation for the R-level
F = the appropriate F-factor
Pt = the perimeter length
HDD = heating degree days
PV = present value of future fuel costs from equation [18]

The insulation costs and F-values are varied until the R-level is found with the lowest lifecycle cost. This method was used to verify the above approach. The model is quite sensitive to the following parameters. They should be determined with care:

1. Cost estimates for insulation levels
2. Building balance point temperature
3. Fuel escalation and discount rates
4. Analysis period

Generally, the results of this study show that economically optimal insulation levels for heated basements are comparable to that of above grade walls, given similar incremental costs. However, the incremental cost of insulating basements on

the interior may be less than that of insulated above grade walls for some interior applications, since additional framing beyond 2 x 4s may not be necessary up to a level of R-30. This results in optimal R-levels for basement walls, above that of above grade ones.

The optimal insulation level of unheated basements is much less than that for heated ones. Optimal levels for crawlspaces are high for those with insulated floors, and lower for insulated crawlspace walls. Optimal insulation levels for slab perimeter insulation are fairly low given the high cost of the insulation material and the low marginal thermal returns.

APPENDIX C

RECOMMENDATIONS FOR BELOW GRADE CONSTRUCTION

This section briefly describes "lessons learned" in the study of energy use in residential below grade configurations. Both heating and cooling issues are addressed.

Heating

1. The temperature maintained in a heated below grade space is the most important determinate of heating energy use. For unheated configurations, the temperature maintained in the above grade portion of the house is the most important factor. Of secondary concern for both is the soil conductivity.

2. Generally, the most energy intensive building technique is the heated shallow or daylight basement.

3. Vented crawlspaces with insulated floors are the most efficient building technique, but freezing may be a problem in very cold climates. Other efficient configurations are unheated basements, all-weather wood foundation crawlspaces, and slab on grade types. Heated basements are the most efficient earth contact building method if one considers the energy use on the basis of conditioned space area. Unheated basements lose about half as much heat as a heated basement.

4. Substantial heat loss reductions in basements are achieved by installing modest amounts of insulation. R-11 wall insulation reduces heating energy needs to one-half of that required for an uninsulated basement.

5. Exterior insulations on basement walls are slightly superior to interior placement in a thermal sense. However, this effect is small and may easily be overshadowed by practical concerns. Exterior insulation is especially effective if only the upper half of the wall is to be insulated, or for use with shallow basement types. Exterior application does have the advantage of enclosing the concrete in insulation and providing a greater effective building heat capacity. Thus exterior insulation may improve passive solar performance.

6. All-weather wood foundations for crawlspaces or basements are thermally superior to the use of concrete walls with the same level of interior or exterior insulation. This is due to the much lower conductivity of the wood. Concrete masonry acts as a vertical thermal fin so that heat migrates readily through to the uninsulated soil around the base of the wall.

7. Half-wall insulation of heated basements is an inferior heat loss control method due to thermal bridging through the stem wall. An overall insulation of R-5 over the entire wall is greatly superior to R-10 over the top half.

8. The point of diminishing returns is reached with all insulation and configuration types at approximately R-20.

9. The optimal level of insulation for heated basement walls is approximately the optimal level for above grade walls. This can be altered, if the cost of below grade insulation is substantially different than that for the walls above, or greater with soils of higher conductivity. In theory the optimal level is tapered, with the highest insulation recommended for just below grade level tapering off to floor level. However, this may not be practical in actual construction.

10. If a heated basement is insulated underneath and is open to the above grade space, then the thermal mass of the floor should be counted in assessing the building heat capacity for judging passive solar effects, setbacks, etc.

11. Perimeter insulation around basement floors is a thermally effective technique. This is especially true for shallow basements.

12. Vertical and horizontal slab insulation are equally energy effective. Practical concerns in construction will outweigh the minor differences in performance.

13. Full horizontal slab insulation is one of the most efficient of all configurations examined and may be warranted in cold climates or when the slab is used as mass storage for a passive solar system.

Cooling

1. Slab floors and basement floors exhibit a very beneficial cooling influence in warmer climates during summer. Crawlspaces have minimal cooling effects.

2. Insulating the top half of a basement wall may be the superior strategy for areas with greater cooling loads. Heat gain through the above grade and near grade level portions are reduced while beneficial heat loss occurs at the base of the wall and floor.

3. Only two feet of slab insulation is warranted in warmer climates. Underfloor insulation is not recommended in these areas since beneficial summer cooling more than offsets the slight increase in winter heating loads.

4. In warm climates, well insulated basements, or unheated types have a net annual energy benefit. They save more cooling energy in summer than they use in the heating season.

5. The superiority of all-weather wood foundations for heating is not demonstrated for warm climates. Beneficial cooling effects from masonry earth contact are lost.

6. Optimal insulation levels probably do not exceed R-10 for cooling concerns although this has not been studied analytically.

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